# Impervious Surface Cover
# Concepts and Thresholds

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## Impervious Surface Cover and Watershed Impacts

The relationship between impervious surface cover and nonpoint source runoff and the concomitant adverse impacts on water quality, aquatic communities, habitat, and water quantity has been well documented in the literature (Schueler 1994; Arnold and Gibbons 1996; May et al. 1997). Although impervious surfaces themselves do not generate pollution, they do induce hydrologic change in a watershed that promote many of the physical and biological changes affecting urban streams (May et al. 1997).

Impervious surfaces can be defined as any material that prevents the infiltration of water into the soil (Arnold and Gibbons 1996). Disruption of natural runoff processes by increases in impervious cover result from the loss of the water-retaining function of the soil in the urban landscape (Booth and Leavitt 1999). If construction results in total removal of the loose upper soil layers for road and building foundations, loss of the water-retaining function of the soil may be absolute. Functional capacity of the water-retaining properties of the soil can be lost to a degree if precipitation falling on paving, rooftops, and other impervious surfaces is routed directly to a stream (Booth and Leavitt 1999). Sidewalks, patios, bedrock outcrops, and compacted soils are examples of other impervious surfaces (Arnold and Gibbons 1996).

Disruption in the natural hydrologic cycle has significant implications with respect to public health and welfare. These include impacts related to flooding, water quality, water supply, habitat and species diversity for both aquatic and terrestrial species, and recreation. As impervious cover increases, surface runoff increases in volume and velocity while infiltration and soil percolation decreases. Stream channels are often highly modified in urban areas to protect adjacent property from erosion (for example, streams are enclosed with storm drains or channels are lined with heavy stone; Caraco et al., 1998), further increasing conveyance of runoff. Increases in runoff volume, coupled with increased water conveyance efficiency through pipes, gutters, and artificially straightened channels, results in more severe flooding (Arnold and Gibbons 1996).

Depending on degree of impervious cover, the annual volume of stormwater runoff can increase by 2-16 times its predevelopment rate with proportional reductions in ground water recharge (Schueler 1994). Caraco et al. (1998) report that the cross-sectional areas of urban streams increase from increased flow and again, depending upon degree of impervious cover and age of development in an upland watershed, streams can widen by a factor of 2 to 5. May et al. (1997) reported that the number of road crossings (bridges and culverts) and stormwater outfalls per kilometer increase at a steady rate as imperviousness increases above 8-10 percent, further confirming the increase in watershed drainage conveyance in conjunction with increasing impervious cover.

In natural settings, very little annual rainfall is converted to runoff and about half is infiltrated into the underlying soils and water table. This infiltrated water supplies aquifers and supports adjacent surface waters with clean water during dry periods. In urbanized areas, less annual rainfall is infiltrated and more volume converted to runoff on a more frequent basis (Caraco et al. 1998). The shift away from infiltration reduces ground water recharge threatening aquifer supplies, as well as impacting ground water base flow to streams, especially during periods of low rainfall (Arnold and Gibbons 1996; Caraco et al. 1998).

Increases in runoff results in erosion not only from construction sites, but also from streambanks. Increases in peak flow and volume gradually erodes and widens unprotected stream channels. Riparian cover can also be lost directly (by bank erosion) or as a result of urban encroachment. This loss in riparian terrestrial habitat also results in changes to the water temperature regime and, hence, in the aquatic communities of streams depending on aquatic species tolerances.

During the summer, impervious areas can have local air and ground temperatures that are 10-12$^{o}$F higher than the vegetative forests or fields they replace (Schueler 1994). Galli (1991 as cited by Schueler 1994) found direct correlations between imperviousness and the degree of summer stream warming when comparing forested reference streams to urban streams. Impervious surfaces, ponding, and poor riparian cover in urban watersheds can increase mean summer stream temperatures by 2-10$^{o}$ F (Caraco et al. 1998). For New Jersey, moderate increases in stream temperature can affect temperature sensitive organisms such as trout species.

May et al. (1997) report that riparian conditions (such as buffer width, vegetative condition, and longitudinal connectedness of buffer vegetation) were influenced by the level of development. Wide buffers (greater than 30 m) were found to decrease as impervious cover increased. Fragmentation of the riparian corridor was related to increased urbanization as defined by increased impervious cover. In 22 streams studied, only the natural streams (those with less than 5-percent impervious area) had a substantial portion of their riparian corridor as mature forest (May et al. 1997). Increased soil erosion, salt exposure, seed and pathogen dispersal from roads during and after construction result in direct and indirect impacts to vegetative cover through increased invasive species introduction, susceptibility to pathogens, revegetative inhibition, and foliar damage (Reid 1993).

Increased watershed erosion and stream bank degradation brings about increases in downstream sedimentation and pollutant transport. Concomitant increases in water turbidity have implications for both drinking water treatment as well as reservoir capacity (Caraco et al. 1998).

Increased sedimentation also results in the loss of natural in-stream habitats such as pebbles, rock ledges, and deep pools that, in turn, will alter aquatic ecology. Pollutant transport includes fecal coliform, other pathogens, increased nutrient loading, heavy metals, and toxic organic pollutants such as pesticides. Caraco et al.(1998) cite an increase in post-development phosphorous loads above background phosphorous loads once 20-25 percent imperviousness is exceeded. Taken individually, as well as collectively, these pollutants have adverse direct and indirect effects on water quality, human consumption of fish and shellfish, recreational water use, and resident biota, as well as predator species reliant upon aquatic food sources (Arnold and Gibbons 1996; Caraco et al. 1998). Specific data analyses for New Jersey on bed sediment chemistry (Stackelberg, 1996, 1997; O’Brien, 1997a, 1997b); pesticides (O’Brien and others, 1997;

Reiser and O'Brien, 1998a), volatile organic compounds (Reiser and O'Brien, 1998b; Reiser, 1999), and aquatic communities (Kennen, 1998 and 1999; Kennen and Kurtenbach, 2000; Chang and others, 2000) indicate significant relations between variations in stream-water quality and land-use patterns.

Schueler (1994) and Arnold and Gibbons (1996) cite various studies indicating that above a threshold of 10-percent watershed imperviousness, benthic macroinvertebrate diversity declines. At higher impervious cover levels, sensitive aquatic species such as stoneflies, mayflies, and caddisflies are replaced by more pollutant tolerant species such as chironomids, tubificid worms, amphipods, and snails. Klein (1979) reported that stream quality impairment (using benthic macroinvertebrate, as well as indicator fish species) in the Piedmont province of Maryland is first evidenced when watershed imperviousness reaches 12%, but does not become severe until imperviousness reaches 30%. Jones and Clark (1987) reported that watershed urbanization has a major impact on benthic insect communities even in the absence of point source discharges. Using human population densities in the watershed drainage, Jones and Clark (1987) reported that species diversity and species richness decreased and chironomid and dominance increased with increasing urbanization. When comparing relative abundances of benthic species, Jones and Clark (1987) report observing a distinct "separation" between low and nonurbanized streams at <10 humans per hectare compared to more heavily urbanized streams with >10 humans per hectare.

Other fish abundance and community surveys also show an inverse relationship with increasing urbanization . Steedman (1998) tested species richness, abundance and incidence of disease in a multivariate study of stream quality. Steedman (1998) reported lowest Indices of Biotic Integrity in watershed with less than about 10% forest cover or riparian forest. Schueler (1994) cites the work of Galli (1994); Luchetti and Feurstenburg (1993); and Klein (1979), as well as others, demonstrating the loss of sensitive fish species as impervious cover increases. Sensitive species, such as trout and sculpin were lost as imperviousness increased above 10 percent, with a second threshold demonstrated at about 25-percent impervious cover (Schueler 1994).

Recent studies suggest a10-percent impervious surface threshold may apply to wetland communities as well (May et al. 1997). Hicks (1995) demonstrated a direct negative correlation between wetland habitat quality and increasing impervious surface area in Middlesex County, Connecticut watersheds that is consistent with the 10-percent threshold as applied to habitat impairment. Data by Taylor (1993) as reported by Schueler (1994) show annual wetland fluctuations occurred consistently when upstream watersheds exceed 10-15 percent imperviousness. The richness of wetland plant and amphibian communities in this study dropped with increases in annual wetland fluctuations.

### Thresholds

There is evidence in the scientific literature that there is a link between impervious surface cover and stream ecosystem impairment, some researchers have suggested that impairment begins to be significant at approximately 10-percent impervious surface cover (Schueler 1994; Arnold and Gibbons 1996; May et al. 1997). Recent research has also shown that the amount of impervious cover in a subwatershed can be used to project the current and future quality of many headwater streams. There are also strong lines of evidence that suggest that impervious cover is linked to the quality of other subwatershed resources such as lakes, reservoirs, estuaries, and aquifers (Caraco et al. 1998).

Caraco et al. (1998) define subwatersheds as typically having a drainage area of 2-15 $mi^2$ with boundaries that include land area draining to a point at or below the confluence of two second order streams and almost always within the limits of a third order stream. The influence of impervious cover on hydrology, water quality and biodiversity is most evident at the subwatershed level where the influences of individual development projects are easily recognizable. Hence, the relationship of impervious cover to a subwatershed unit (typically 1-10 $mi^2$) is categorized as strong, while the influence of impervious cover within a watershed unit (typically 10-100 $mi^2$) is categorized as moderate (Caraco et al. 1998).

The relationship between impervious cover and subwatershed quality has been clearly demonstrated above. As cited, stream research generally indicates certain zones of stream quality exist where, most notably at about 10-percent impervious cover, sensitive stream elements are lost from the system. Increased impervious cover corresponds to a lower aquatic insect diversity; decline of biological function; fish egg and larval survival decline; decline in plant and amphibian density with increases in water fluctuation in wetlands; decline in riparian cover; decline in channel stability; and fish habitat quality decline (Caraco et al. 1998). A second threshold appears to exist at around 25-30 percent impervious cover where most indicators of stream quality consistently shift to a poor condition (e.g., diminished aquatic diversity, water quality and habitat scores).

Consistent with Caraco et al. (1998), the NJDEP has defined a subwatershed on a 14-digit Hydrologic Unit Code or HUC-14 basis. The 900 HUC-14 subwatersheds in New Jersey have an average drainage area of 8.6 square miles, a range of 2.3 to 42.0 square miles, and a standard deviation of 4.0 square miles (data from Ellis, 1995; as modified by unpublished USGS/NJDEP collaborative update, January 2000) These statistics exclude the large offshore HUC polygons that are mostly water. Based upon the scientific literature, Caraco et al. (1998) cite an impervious cover model that classifies urbanizing streams into the following three categories: sensitive streams; impacted streams, and non-supporting streams on a subwatershed basis.

<u>Sensitive streams</u> typically have a watershed impervious surface cover from 0–10 percent. Consequently, sensitive streams are of high quality, typified by stable channels, excellent habitat structure, good to excellent water quality, and diverse fish communities.

<u>Impacted streams</u> possess watershed impervious cover ranging from 11-25 percent and show clear signs of degradation due to urbanization. Greater frequency and volume of storm flushing begins to alter stream geometry. Erosion and channel widening are clearly evident. Streambanks become unstable, and physical habitat in the stream declines noticeably. Stream water quality shifts into the fair/good category during both storms and dry weather periods; biodiversity declines to fair levels, and the most sensitive fish and aquatic insects disappear from the stream.

<u>Non-supporting streams</u> cross a second threshold whereby impervious cover is greater than 25 percent. At this level of impervious cover, streams are essentially conduits for stormwater flow and can no longer support a diverse stream community. Stream

channels in this category are highly unstable, can experience severe widening and erosion. Pool and riffle structure for aquatic habitat is diminished resulting in substrate loss for aquatic insects, benthic macroinvertebrates, and fish spawning. Water quality is consistently rated as fair to poor and contact recreation is no longer possible due to the presence of high bacterial levels. Caraco et al. (1998) conclude that these streams generally display increases in nutrient loads downstream even if effective urban Best Management Practices (BMPs) are installed and maintained. Arnold and Gibbons (1996) report a similar secondary threshold of 30 percent at "which degradation becomes so severe as to become almost unavoidable".

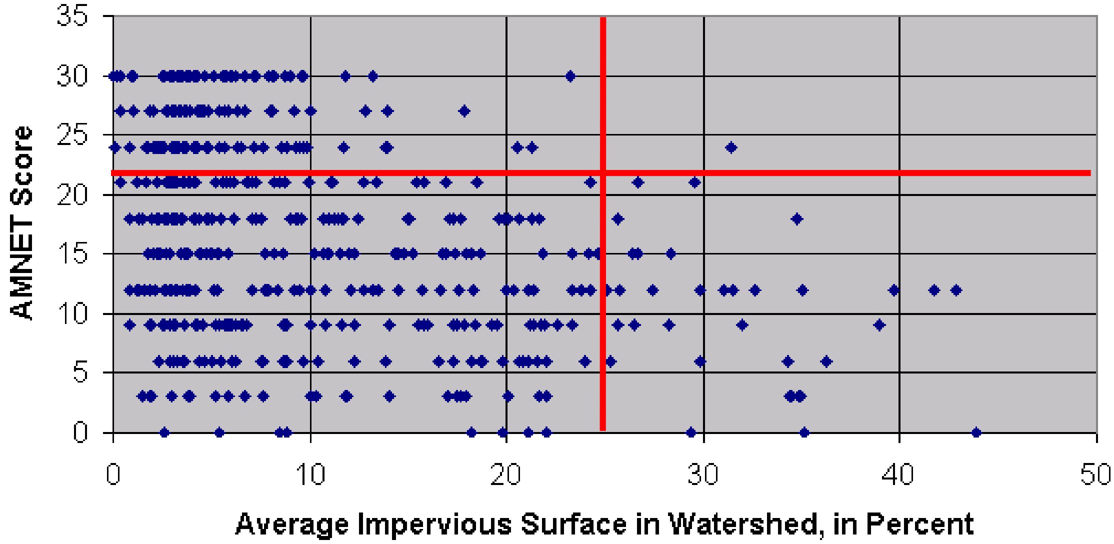
The thresholds, as cited by Caraco et al. (1998), are a synthesis of the scientific literature and apply to subwatersheds. The stream classification thresholds follow a progressive scheme in which increasing impervious cover is directly related to decreasing water quality. The NJDEP secondary threshold of greater than 25-percent impervious cover is derived from this understanding that when the average impervious cover within a HUC-14 subwatershed exceeds 25 percent, the likely result is a change in hydrologic regime where streams essentially function as stormwater conduits and a diverse biological community can no longer be supported.

These classifications are based upon the average behavior of stream indicators over a range of impervious cover. Some streams outside of the threshold range (either higher or lower) could exhibit impacted characteristics rather than characteristics associated with non-supporting streams. For planning purposes, however, this model attempts to predict the expected transition of a composite of individual stream indicators based upon best available scientific evidence using impervious area as the index.

In New Jersey, the current statewide data on benthic invertebrate communities in the ambient biomonitoring network (AMNET; NJDEP, 1994) tend to support the proposed model. The benthic invertebrate communities at all but one of the AMNET stream sampling sites in small watersheds (less than 20 mi2) with an average impervious surface above 25 percent are moderately to severely impaired (Figure 1). This fact lends support to the use of the 25-percent threshold as an index. The AMNET scores are the sum of 5 separate metrics or measures of community health at a site (Kurtenbach, 1994; NJDEP, 1994). AMNET scores of 21 or less indicate moderately impaired communities; severely impaired communities have scores of 9 or less. The rest of the plot indicates that the relation of AMNET score to impervious area, by itself, is not strong (for example, low scores at low levels of impervious surface) but, as the review above notes, there are a lot of other reasons that a site might be impaired. Impervious area is only one indicator of the stresses urban development has on aquatic communities.

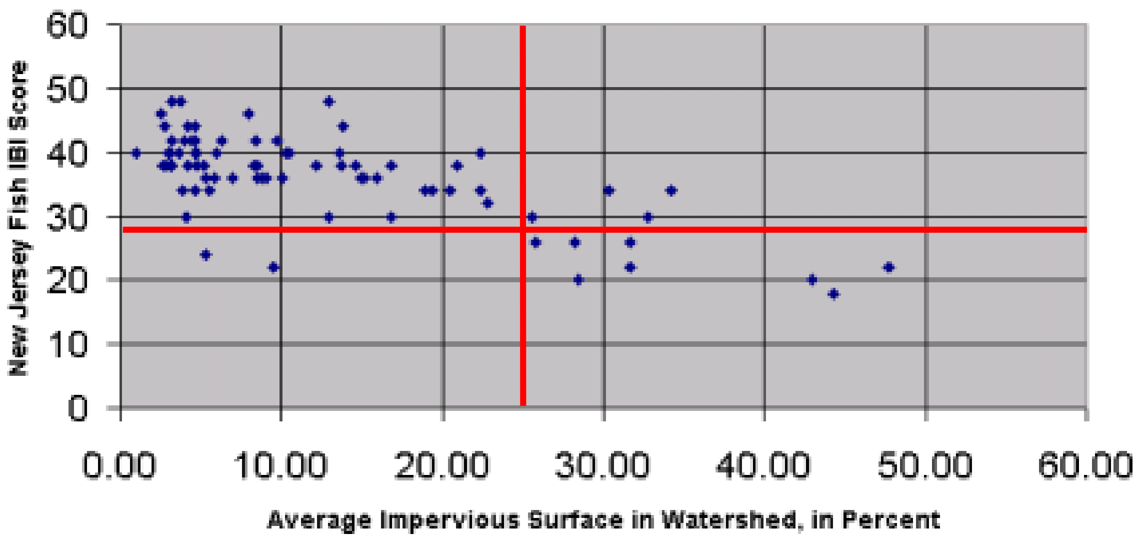
The available fish community data from a recent USEPA study of New Jersey streams (Kurtenbach, 1993) also supports the indicator concept of the 25-percent index threshold of average impervious surface area presented above. Fish IBI scores are a composite of 5 separate metrics or measures of community health at each site (Kurtenbach, 1993). Fish

Figure 1. Relation of AMNET score to average impervious surface in watersheds less than 20 square miles for 510 NJDEP sites in New Jersey.




IBI scores less than 28 are impaired. Eight of the twelve sites above the 25-percent impervious area threshold are impaired (Figure 2); the other four sites are just above the impairment level. There are two sites that are impaired that are well below the 25-percent impervious threshold, but like the many benthic invertebrate sites that are impaired at low levels of watershed imperviousness, all these sites are impaired for other reasons; some obvious like point source influence, some not so obvious.

Figure 2. Relation of fish IBI score to average impervious surface in watersheds less than 20 square miles for 79 USEPA sites in New Jersey.



In some instances, particularly in the future, implementation of urban BMPs, riparian buffer conservation/restoration, and/or urban retrofitting efforts may be able to mitigate the effects of impervious area and thereby shift the impervious cover thresholds to a higher percentage. Quite possibly, water-quality improvements could potentially be realized in areas now considered to be non-supporting streams. The NJDEP intent, where average impervious surface within a HUC14 subwatershed exceeds 25-percent, is to address these issues during the Watershed Management Area planning process.

**Notes on the Determination of Impervious Surface Percent**

The average impervious surface cover for a HUC-14 for this threshold analysis will be derived from the NJDEP Bureau of Geographic Information and Analysis 1995/97 Land Use/Land Cover (LULC) data set for New Jersey. About half of the LULC data are currently available (February 2000). The data are based upon statewide digital aerial photography taken in 1995 and 1997. All polygons within New Jersey that are classified as urban, built-up, commercial, industrial, transportation, utilities, recreational, mining, or altered lands have been assigned an impervious surface cover value between 0 percent and 100 percent, at 5 percent intervals.  Access to these data is facilitated through the NJDEP website www.state.nj.us/dep/gis or by calling 609-777-0672.

The impervious surface calculations used for illustration in Figures 1 and 2 (and as an interim to the availability of the photo interpreted LULC data above) were derived from an index to total average impervious surface computed from two sources (USGS, 2000). The first source was a direct computation of roadway impervious area from the 1995/97 NJDOT roads coverage by assuming a 10-meter average road width. The second source was a computation of non-road impervious area from a statistical relation developed between the available 1995/97 LULC data above for 3 major watersheds (Hackensack, Whippany, and Rancocas) and housing-density data from the 1990 Bureau of Census. The statistical relation developed from the 3 watersheds was then extrapolated to the rest of New Jersey with the statewide coverage of housing-density data. Statewide commercial and industrial areas were assigned the average impervious surface of 70 percent from the 3 watersheds. Road, non-road, and commercial/industrial impervious surface estimates were summed for New Jersey and the average impervious surface percentage was calculated for each of the study watersheds in Figures 1 and 2 (data from the USGS, West Trenton, New Jersey).

References

Arnold, C.L. Jr. and C.J. Gibbons. 1996. Impervious Surface Coverage The Emergence of a Key Environmental Indicator. Journal of the American Planning Association 62(2): 243-258.

Booth, D.B. and J. Leavitt. 1999. Field Evaluation of Permeable Pavement Systems for Improved Stormwater Management. Journal of the American Planning Association 65(3): 314-326.

Caraco, D., R. Claytor, P. Hinkle, H. Kwon, T. Schueler, C. Swann, S. Vysotsky, and J. Zielinski.  1998. Rapid Watershed Planning Handbook. A Comprehensive Guide for Managing Urbanizing Watersheds.  Prepared by Center For Watershed Protection, Ellicott City, MD. Prepared for U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds and Region V. October 1998.

Chang, Ming, J.G. Kennen, E. Del Corso. 2000. Evaluating Temporal Changes in Stream Condition in Three New Jersey River Basins By Using an Index of Biotic Integrity. The Bulletin of the New Jersey Academy of Science (Accepted for publication).

Ellis, W.H., Jr. and Price, C.V., 1995, Development of a 14-digit hydrologic coding scheme and boundary data set for New Jersey: U.S. Geological Survey Water Resources Investigations Report 95-4134, 1 sheet.

Galli, J. 1991. Thermal Impacts Associated with Urbanization and Stormwater Management Best Management Practices. Metropolitan Washington Council of Governments. Washington, D.C. 188 pp. (As cited by Schueler 1994).

Galli, J. 1994. Personal communication. Department of Environmental Programs, Metropolitan Washington Council of Governments, Washington, DC. (As cited by Schueler 1994).

Hicks, A.L. 1995. Impervious Surface Area and Benthic Macroinvertebrate Response as an Index of Impact from Urbanization on Freshwater Wetlands. M.S. Thesis, Department of Forestry and Wildlife Management, University of Massachusetts, Amherst, MA.

Jones, R. and C. Clark. 1987. Impact on Watershed Urbanization on Stream Insect Communities. American Water Resources Association. Water Resources Bulletin. Kennen, J.G. 1998. Relation of benthic macroinvertebrate community impairment to basin characteristics in New Jersey streams: U.S. Geological Survey Fact Sheet FS-057-98, 6p.

Kennen, J.G. 1999. Relation of macroinvertebrate community impairment to catchment characteristics in New Jersey streams: Journal of the American Water Resources Association, 33(2), p. 939-955.

Kennen, J.G., and Kurtenbach, J.P. 2000. An integrated approach evaluating the relation between fish community condition and basin characteristics in northern New Jersey streams: journal article, (in review)

Klein, R. 1979. Urbanization and Stream Quality Impairment. American Water Resources Association. Water Resources Bulletin 15(4).

Kurtenbach, J. 1993. Index of biotic integrity study--New Jersey--Passaic, Wallkill, Delaware and Raritan drainages, summer 1990-1993. U. S. Environmental Protection Agency. 32 pp. plus app.

Kurtenbach, J.P. 1994. Methods for Rapid Bioassessment of Streams Using Benthic Macroinvertebrates. U.S. Environmental Protection Agency, Ambient Monitoring Section, 13 pp.

Luchetti, G. and R. Fuersteburg. 1993. Relative Fish Use in Urban and Non-Urban Streams. Proceedings: Conference on Wild Salmon. Vancouver, British Columbia. (As cited by Schueler 1994).

May, C.W., R.R. Horner, J.R. Karr, B.W. Mar, E.G. Welch. 1997. Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion. Watershed Protection Techniques 2(4): 483-493.

New Jersey Department of Environmental Protection (NJDEP). 1994. The Establishment of Ecoregion Biological Reference Sites for New Jersey Streams. Bureau of Water Monitoring, Trenton, New Jersey, 17 pp.

O'Brien, A.K. 1997a. Presence and distribution of trace elements in New Jersey streambed sediments, U.S. Geological Survey Fact Sheet FS-049-97.

O'Brien, A.K. 1997b. Presence and distribution of trace elements in New Jersey streambed sediments, Journal of the American Water Resources Association, 33(2), p.387-403.

O'Brien, A.K., Reiser, R.G., and Gylling, Helle. 1997. Spatial variability of volatile organic compounds in streams on Long Island, NY, and in New Jersey: U.S. Geological Survey Fact Sheet FS-194-97, 6p.

Reid, L. 1993. Research and Cumulative Watershed Effects. United States Department of Agriculture, Forest Service, Pacific Southwest Research Station, General Technical Report PSW-GTR-141.118 pp.

Reiser, R.G., and O'Brien, A.K. 1998a. Pesticides in streams in New Jersey and on Long Island, NY and relation to land use: U.S. Geological Survey Water Resources Investigation Report 98-4261, 12p.

Reiser, R.G., and O'Brien, A.K. 1998b. Occurrence and seasonal variability of volatile organic compounds in seven New Jersey streams: U.S. Geological Survey Water Resources Investigation Report 98-4074, 12p.

Reiser, R.G. 1999. Relation of pesticide concentrations to season, streamflow, and land use in seven New Jersey: U.S. Geological Survey Water Resources Investigation Report 99-4154, 19p.

Schueler, T. 1994. The Importance of Imperviousness. Watershed Protection Techniques 1(3): 100-111.

Stackelberg, P.E., 1996, Presence and distribution of chlorinated organic compounds in New Jersey streambed sediments, U.S. Geological Survey Fact Sheet FS-118-96.

Stackelberg, P.E., 1997, Presence and distribution of chlorinated organic compounds in New Jersey streambed sediments, Journal of the American Water Resources Association, 33(2), p. 271-284.

Steedman, R.J. 1988. Modification and Assessment of an Index of Biotic Integrity to Quantify Stream Quality in Southern Ontario. Canadian Journal of Fisheries and Aquatic Sciences 45:492-501).

Taylor, B.L. 1993. The Influences of Wetland and Watershed Morphological Characteristics and Relationships to Wetland Vegetation Communities. Master’s Thesis. Department of Civil Engineering, University of Washington, Seattle, WA. (As cited by Schueler 1994).

United States Geological Survey (USGS). 2000. History (Metadata) of grid development for multivariate and other analyses of NAWQA urban gradient data (Last Update: February 2000): U.S Geological Survey (Accessed February 2000 on the World Wide Web at URL http://nj.usgs.gov/nawqa/rdmegrid.htm).

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